Navigation of LICIACube: Challenges and Lessons learned

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Recently, the advances in science instruments and spacecraft miniaturization technologies pushed the CubeSats beyond their typical low Earth orbit applications. The deep space represents the new frontier for the SmallSats, either as stand-alone missions, or as companions to larger missions on which they could "catch a ride" to the most remote and challenging destinations in the Solar System.

The Light Italian Cubesat for Imaging of Asteroids, *LICIACube*, is a 6U CubeSat mission of the Italian Space Agency (ASI), developed and operated by the Italian company Argotec, under ASI coordination and with the contribution of several Italian Research Institutions. *LICIACube* participated in the NASA's planetary defense *DART* mission, which tested the effectiveness of kinetic deflectors by impacting into the secondary asteroid of the Didymos system, Dimorphos. *LICIACube* provided unique pictures of the post-impact scene, acquired during a single high-speed flyby of the Didymos asteroid system, supporting the energy exchange investigations.

On September 11, 2022, the CubeSat was released from the *DART* piggyback dispenser and started its independent approach to the system. Few hours later, the navigation operations of *LICIACube* kicked-off. For the following 15 days, different orbital and desaturation manoeuvres were designed and executed, leading *LICIACube* towards the predefined location to observe *DART*'s impact on Dimorphos. On September 26, 2022, about 168 seconds after *DART*'s impact, *LICIACube* flew by the asteroid at ~58 km and ~6.1 km/sec, capturing images of the impact, the ejecta plume and the non sun-lit side of Dimorphos, becoming the first CubeSat to flyby an asteroid in deep space. After the impact, the spacecraft continued on its trajectory while downloading the acquired images to the Mission Control Centre until December 23, 2022, when following an ASI decision, the spacecraft was commanded to execute the end-of-life procedure, and subsequently the end of mission was declared.

The navigation strategy of *LICIACube* relied on classical two-way radiometric data, range and range-rate observables, and has been performed independently by both the University of Bologna (UNIBO) and the JPL, using JPL's orbit determination software MONTE. This work discusses the navigation processes performed by the UNIBO flight dynamics team in order to support efficient and accurate navigation operations. In addition, it covers the challenges and the lessons learned on deep space CubeSat navigation.